# NON-VOLANT RODENT ABUNDANCE AND DAMAGE, DIET PREFERENCE AND CONTROL USING ANTICOAGULANT RODENTICIDE IN OIL PALM PLANTATION, SUNGKAI, PERAK

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**by**


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| | |
|---|---|
| AR | Anticoagulant rodenticide |
| EIL | Economic Injury Level |
| ETL | Economic threshold level |
| FFB | Fresh fruit bunches |
| FGAR | First-generation anticoagulant rodenticide |
| g | Gram |
| IPM | Integrated Pest Management |
| kg | Kilogram |
| mm | Millimeter |
| PCA | Pearson Correlation Analysis |
| SGAR | Second-generation anticoagulant rodenticide |
| SPSS | Statistical Package for Social Science |
| µg | Microgram |

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**TABURAN RODEN TIDAK TERBANG DAN KEROSAKAN KEPADA BUAH SAWIT, PILIHAN DIET DAN KAWALAN MENGGUNAKAN RACUN TIKUS ANTI-GUMPALAN DI LADANG KELAPA SAWIT, SUNGKAI, PERAK**

## ABSTRAK

Perosak tikus menyebabkan kerugian ekonomi yang ketara kepada industri kelapa sawit, memerlukan pemahaman yang mendalam tentang taburan spesis, tingkah laku dan kaedah kawalan yang berkesan. Sebanyak 132 ekor tikus telah ditangkap menggunakan perangkap tikus di Sungkai Perak, dengan 82.58% adalah tikus rumah Malaysia (*Rattus rattus diardii*). Ukuran fizikal *R. rattus diardii* jantan dan betina menunjukkan tiada perbezaan. Purata ukuran ialah: berat 158.73±4.63g, panjang kepala ke badan 136.73±2.99mm, panjang ekor 169.51±3.24mm, panjang telinga 20.68±0.20mm, panjang kaki belakang 32.64±0.29mm, dan panjang gigi kacip atas 2.86±0.04mm. Kajian ini juga menilai hubungan antara saiz populasi *R. rattus diardii*, bilangan buah tandan segar (BTS), dan kerosakan kepada BTS kelapa sawit yang masak dan belum masak. Hubungan positif yang ketara dinilai antara kejayaan perangkap dan kerosakan BTS (korelasi Pearson: $r = 0.628$, $p < 0.001$). BTS masak mempunyai purata kerosakan yang lebih tinggi (7.72 ± 0.66%) berbanding BTS yang belum masak (6.01 ± 0.38%), tetapi perbezaannya tidak signifikan secara statistik (Ujian t sampel bebas: $P>0.05$). Dalam ujian makmal, *R. rattus diardii* menunjukkan keutamaan diet tertinggi untuk pisang, dengan kadar penerimaan 83.84% dan nisbah pemakanan 1:5 berbanding biji relai kelapa sawit. Ini menunjukkan tanaman integrasi antara pisang dan kelapa sawit berpotensi untuk menarik perhatian tikus ke ladang kelapa sawit tetapi pisang juga boleh dipertimbangkan untuk dijadikan umpan yang sesuai untuk mengawal tikus. Seterusnya, keberkesanan umpan racun tikus dinilai oleh kerosakan tikus segar pada BTS, penerimaan umpan, dan kejayaan perangkap. Racun tikus yang digunakan dalam kajian ini, 0.005% Brodifacoum (T4), 0.003% Brodifacoum (T3), dan 0.005% Chlorophacinone (T1) mengurangkan kerosakan tikus di bawah tahap ambang ekonomi (ETL) sebanyak 5% menjelang pusingan ke-2 umpan, manakala 0.010% Chlorophacinone (T2) mencapainya pada pusingan ke-3. Penerimaan umpan turun ke 20% menjelang pusingan ke-5 untuk semua rawatan kecuali T4 (pusingan ke-4). Secara keseluruhan, semua umpan berkesan mengurangkan kerosakan di bawah 5% ETL pada pusingan ke-3 dan penerimaan umpan jatuh di bawah 20% pada pusingan ke-5, dengan purata pengurangan populasi tikus sebanyak 85.25% di kawasan yang dirawat berbanding 5.26% dalam kawalan. Keputusan menyimpulkan bahawa racun brodifacoum dan chlorophacinone sangat berkesan dalam mengawal populasi *R. rattus diardii* di ladang kelapa sawit. Kajian ini menyimpulkan bahawa menguruskan perosak tikus di ladang kelapa sawit memerlukan pemahaman tingkah laku spesies, hubungan antara keutamaan dan risiko kerosakan kepada tanaman, dan menggunakan racun tikus dengan berkesan. Penemuan utama mengenai kelaziman *R. rattus diardii*, keutamaan diet dan keberkesanan racun tikus memberikan garis panduan untuk mengawal serangan masa depan dengan berkesan.

**NON-VOLANT RODENT ABUNDANCE AND DAMAGE, DIET PREFERENCE AND CONTROL USING ANTICOAGULANT RODENTICIDE IN OIL PALM PLANTATION, SUNGKAI, PERAK**

## ABSTRACT

Rodent pests cause significant economic loss to the oil palm industry, necessitating a deep understanding of their species distribution, behaviour and effective control methods. A total of 132 rodents were captured through live trapping in Sungkai Perak, with 82.58% being Malaysian house rats *(Rattus rattus diardii*). Physical measurements of male and female *R. rattus diardii* showed no differences. Average measurements were weight 158.73±4.63g, head-to-body length 136.73±2.99mm, tail length 169.51±3.24mm, ear length 20.68±0.20mm, hindfoot length 32.64±0.29mm, and upper incisor teeth 2.86±0.04mm. This study evaluated the relationship between *R. rattus diardii* population size, fresh fruit bunch (FFB) availability, and damage to ripe and unripe oil palm FFB. A significant positive relationship was found between trap success and FFB damage (Pearson correlation: $r = 0.628$, $p < 0.001$). Ripe FFB had a higher mean damage (7.72 ± 0.66%) compared to unripe FFB (6.01 ± 0.38%), but the difference was not statistically significant (Independent samples t-test: $P>0.05$). In lab tests, *R. rattus diardii* showed the highest diet preference for bananas, with an 83.84% acceptance rate and a feeding ratio of 1:5 compared to oil palm loose fruits. This suggests intercropping of oil palm with bananas can attract rats to oil palm fields, but banana can also be considered for developing palatable baits for rodent control. Next, rodenticide bait efficacy was evaluated by fresh rat damage on FFB, bait acceptance, and trap success. The rodenticide used in this study, 0.005%

Brodifacoum (T4), 0.003% Brodifacoum (T3), and 0.005% Chlorophacinone (T1) reduced rat damage below the economic threshold level (ETL) of 5% by the 2nd round of baiting, while 0.010% Chlorophacinone (T2) achieved this by the 3rd round. Bait acceptance fell below 20% by the 5th round for all treatments except T4 (4th round). Overall, all baits effectively reduced damage below 5% ETL by the 3rd round and bait acceptance fell below 20% by the 5th round, with an average rodent population reduction of 85.25% in treated areas compared to 5.26% in the control. The results conclude that brodifacoum and chlorophacinone rodenticides are highly effective in controlling *R. rattus diardii* populations in oil palm plantations. The study concludes that managing rodent pests in oil palm plantations requires understanding species behaviour, the relationship between preference and damage risk to crops, and using rodenticides effectively. Key findings on *Rattus rattus diardii* prevalence, diet preferences, and rodenticide efficacy offer a guideline for controlling future infestations effectively.

# CHAPTER 1

# GENERAL INTRODUCTION

Rats infestation in mature oil palm plantation affect the yield of oil palm production by causing damage to the fruit bunches up to 10% (Wood and Chung, 2003). Rats display adaptability, assertive competitiveness, predatory behavior, and resistance to control. (Takashi and Miczek, 2014). According to Basri and Halim, (1985), Over two decades ago, the estimated losses in crop production for the Malaysian oil palm industry surpassed 100 million Malaysian ringgit. Given the subsequent expansion of oil palm plantations during this period, it is probable that these losses have further escalated (Carter et al. 2007).

There are three major rat species in oil palm plantation, *Rattus tiomanicus* (Malayan wood rat), *Rattus argentiventer*, (Rice field rat), and *Rattus rattus diardii* (Malaysian house rat) (Corley and Tinker, 2015). A comprehensive study conducted over an extended period revealed that the rat population in an uncontrolled Malaysian oil palm plantation exhibited gradual fluctuations, ranging from 200 to 500 rats per hectare (Wood and Liau, 1984). According to a survey conducted by Hafidzi and Saayon (2001), *R. tiomanicus* was the most frequently reported species, surpassing *R. argentiventer* and *R. rattus diardii* in prevalence. However, species change, or replacement may occur due to baiting strategy (Lam et al. 1982), propagation of the pollinating weevil, *Elaeidobius kamerunicus* as a source of protein (Liau, 1985), and predator feeding preference on its prey (Zainal Abidin et al., 2017).

There is very few information available on *R. rattus diardii* population dynamics studied in oil palm plantations compared to *R. tiomanicus*. Thus, this study attempts to assess the population abundance and body condition of *R. rattus diardii* in oil palm plantation located in Sungkai, Perak. Moreover, this study assessed the oil palm fruit bunches availability and their relationship with the *R. rattus diardii* population. This information will provide information on the impact of *R. rattus diardii* population on damage severity of the fruit bunches of oil palm.

Rats on oil palm plantations are omnivorous animals that primarily feed on the oil palm fruit bunches. The research on diet preferences of rat pests is largely limited. The diet preference involves the selection of favoured food by the rat species. Hence, studying the feeding preferences of *R. rattus diardii* can contribute to identifying its favored plant-based diet. Wood and Liau (1984) emphasized the importance of conducting numerous observations on the dietary preferences of rodent pest species to improve strategies for rodent pest management.

The primary method for rat control in oil palm plantations has been the utilization of poison baiting with anticoagulants (Wood and Chung, 2003). Wood (1976) established that a 5% occurrence of fresh rat damage indicates an economically threshold level (ETL). Following the application of rodenticides, the level of fresh rat damage should decrease to zero and persist at that point for several months. Additionally, optimal control can be achieved by employing anticoagulant rodenticide with one bait per palm, implementing replacement rounds of baiting at 4-day intervals until bait acceptance drops below 20%. Baiting is conducted at 6-month intervals to minimize the intermediate rat population or damage accumulation. Anticoagulant rodenticides, acting as vitamin-K antagonists, disrupt normal blood clotting and induce capillary damage (Watt et al., 2005).

Anticoagulants are commonly categorized as "first-generation," which includes warfarin, chlorophacinone, and diphacinone, and "second-generation," which comprises brodifacoum and bromadiolone. Warfarin developed resistance and is now widespread in Malaysia (Lam, 1984; Wood and Chung, 1990). Upon the resistance development, second-generation anticoagulant rodenticides (SGARs) such as brodifacoum and bromadiolone have proved effective since the 1980s for pest management. The World Health Organization classifies all these anticoagulants as Type 1A pesticides, necessitating their phase-out under the sustainability criteria outlined by the Roundtable for Sustainable Palm Oil (RSPO).

The objectives of this study were:

1. To evaluate the species abundance of rats and physical measurements of major rat species in oil palm plantation at Sungkai, Perak.
2. To examine the relationship between abundance of major rat species and fresh damage on oil palm fruit bunches.
3. To determine the diet preference of *R. rattus diardii* on plant-based diet.
4. To evaluate the field efficacy of brodifacoum and chlorophacinone against *R. rattus diardii*

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Rodentia

The mammals from order Rodentia represent the largest order up to 40% and compromising 2277 species from 34 families (Krubitzer et al., 2011). The term for the order is derived from the Latin word "rodere," which means to gnaw. The incisors of rodents are notable for their length, with the open roots of the lower pair extending almost to the jaw's articulation. Additionally, their structure is distinctive, as only the front surface is covered with enamel, as noted by Buckle and Smith (2015). This enamel wears down at a slower rate compared to the softer dentine behind it, resulting in a self-sharpening blade. The incisor teeth are important for the rodent to eat, collect material to build nest, carry food and for defense purposes (Chellappan, 2021; Buckle and Smith, 2015). Rodents are classed into three suborders which is Sciuromorpha (e.g., Squirrels), Myomorpha (e.g., Mice and rats) and Hystricomorpha (e.g., Porcupines and cavies). True rats and mice (subfamily Muridae) were believed found in South-east Asia in the late Miocene and an omnivorous, but most of it were herbivorous. The Muridae, also known as murids, constitute the largest rodent family, encompassing two-thirds of both living rodent species and mammals. Murids consist of approximately 1,383 species and majority of them are significant pest species (Aplin et al., 2003). Murids typically exhibit a slender build, with tails that are generally sparsely furred and characterized by distinct scales arranged in concentric rings (Aplin et al., 2003; Buckle and Smith, 2015). Certain murids possess elongated legs and feet, facilitating a hopping motion, while others feature broad feet and tails to enhance climbing abilities, some exhibit neither of these adaptations. Commonly, they are various shades of brown, although many may have markings in black, grey, or white (Timm et al., 2016).

## 2.2 Rodent infestation in Malaysian agriculture

Rodents are among the major constraints to crop production in agriculture and during outbreaks result in significant losses, posing a threat to human's food security (Swanepoel et al., 2017; Krijger et al. 2020; Diagne et al. 2021). The severity of rodent problems is already an established fact in Southeast Asian (SEA) agriculture. The countries in SEA and the Pacific are within the tropic zone, sharing common agroecosystems and some common rodent pest species (Aplin et al. 2003; Buckle and Smith, 2015). In general, rodents are omnivores, primarily consuming plant materials like seeds, leaves, roots, whole young plants, fruit, grain, and tree bark. They also include animal tissue in their diet, such as insects, snails, other invertebrates, and the bodies of vertebrates. (Buckle and Smith, 2015; Diagne et al. 2021).

In rice fields, rodents naturally inhabit open vegetation cover and water courses, moving from these sources into rice fields. As the rice grows, it provides nutrients that can sustain a rapid and abundant increase in pest numbers. Following harvest, when ample food is no longer available, the high population may persist for a period in the straw and stubble of the crop (Brown et al., 2006; Jacob et al., 2010). In Malaysia, the cultivation and export of tropical fruits, such as mango, pineapple, durian, and papaya, contribute to approximately 75% of global fresh tropical fruit production. The production of these commodities has been on the rise since the early 90s. The tropical fruit crop faces minimal pest and disease issues. Lee and Goh (2000) describe the damage and symptoms inflicted by rodents on tropical fruits, including bored holes, striation teeth marks on the fruit husk, feeding on the white succulent pulp inside, and small husk chippings beneath the fruit.

Another rodent infestation on agriculture was studied by Lee (1997) in a cocoa planting area located at Hilir, Perak. It is found that the rodents infested on the cocoa pod and cause damage per population of 0.77 pod damage per animal. In some cases, rodent could cause damage at least four cocoa pods per day (Meriam, 2017). A study by Meriam (2020) found that in the one ha cocoa planting area of about 1455 cocoa tree, a total of 73 rodents were captured using wire mash traps.

Intercropping is a widely practiced agricultural technique employed to optimize land use and enhance crop diversity, especially in immature oil palm smallholder plantations (Koczberski et al. 2012). The choice of profitable intercrops is based on specific agro-climatic conditions and market demands in a given region, including crops like bananas, corn, and pineapples (Nchanji et al., 2016). Intercropping in oil palm plantations presents both advantages and disadvantages. However, a drawback is that these intercrops can also serve as potential food sources or breeding grounds for rats (Whistler and Elevitch, 2006).

## 2.3 Rat infestation in oil palm plantation

Aside from Indonesia, Malaysia holds the position of the world's second-largest producer and exporter of palm oil. As of December 2021, the development of mature oil palm plantation in Malaysia had expanded to 5.7 million hectares, which 89% of the area is fully mature oil palms (MPOB, 2021). Despite the rapid growth of the industry, the oil palm remains threatened by a variety of pests such as insects, vertebrates, and diseases (Corley and Tinker 2015; Woittiez et al. 2017; Kamarudin et al., 2019). Rats are a common major pest in oil palm plantation and the unforeseen effect of the increasing number of rats creates a big concern for oil palm industries (Woittiez et al. 2017). On the early oil palm stage about 30 to 36 months of age, rats could cause severe damage to the fruit bunches and base of palms to get at the bud which can later cause collapse of fronds and even palm death (Chung, 2000; Wood and Chung, 2003). In mature oil palm, rats gnaw on the fruit bunches, even through to the kernels, leaving characteristic scarring, which can be distinguished as ‘fresh’ for two or three days (Buckle and Smith, 2015).

Rats consume the oil-bearing tissue, which constitutes only a relatively small fraction of the total harvested weight of the crop. This makes estimates of losses based on the weights of harvested bunches too insensitive. (Wood and Chung, 2003; Lim et al. 2012). It is suggested that rat-induced damage results in economic losses equivalent to approximately 5% of the average oil yield. This calculation does not account for detached fruitlets carried away by rats but not consumed, potentially elevating the estimate to as much as 10% (Ikhsan et al. 2020; Zainal Abidin et al. 2021). Furthermore, rats are also the main predators on the oil palm weevil, *Elaeidobius kamerunicus* (Ponnamma et al. 2006; Luqman et al., 2017; Mohamad et al. 2022). Rats consume large numbers of larvae, eggs, and pupae that live in the inner part of the spikelet and at the same time destroying the old male inflorescences in the process. Luqman et al. (2017) demonstrated that rats exhibited accelerated growth when their diet was enriched with weevil larvae as a protein source. The introduction of the weevil is believed to have led to an increase in rat populations and the extent of damage inflicted (Yue et al., 2015).

## 2.4 Rat species in Malaysian oil palm plantation

A survey carried out by Hafidzi and Saayon, (2001) confirmed that *R. tiomanicus* is the most reported species of 68% followed by *R. argentiventer* (46%) and *R. rattus diardii* (28%) in Peninsular Malaysia. Another survey conducted by Appanan, et al. (2021) on small vertebrates in an oil palm plantation located in Sime Darby Tangkah Estate located adjacent to Gunung Ledang National Park, Johor found that *R. tiomanicus*, *Maxomys rajah, Tupaia glis,* and *Rattus tanezumi* were presence in the plantation. In FELDA Lahad Datu, Sabah, Phua et al. (2017) recorded that the dominant rodent captured was *R. diardii* of 172 individuals followed by *Rattus whiteheadi* (2 individuals) and *R. argentiventer* (1 individual). Puan et al. (2011) found that in a mature oil palm plantation located at Labu, Negeri Sembilan recorded that majority of the rats captured were *R. rattus diardii*, followed by *R. argentiventer* and *R. tiomanicus*.

In a study conducted in Chuping, Perlis, Malaysia, within an oil palm plantation that was previously a sugarcane plantation, a significant infestation of *Bandicota indica* was documented. The observed damage symptoms included conspicuous feeding marks on fruitlets, inflorescences, and even premature palm trees (Shukor et al. 2018). The rat species abundance was studied by Zainal Abidin, and Noor Hisham, (2015) in Felda Global Ventures (FGV) on five primary regions for oil palm cultivation in Sabah and Sarawak, Malaysia. From the study, it is found that *R. rattus diardii* was the most dominant (61.34%) followed by *Rattus exulans* (11.79%), *Maxomys whiteheadi* (8.37%), *R. tiomanicus* (3.93), and R. *argentiventer* (1.14%). A recent study by Nasir et al. (2022) on rat abundance found that *R. tiomanicus*, *R. argentiventer*, *R. rattus diardii*, *Rattus exulans* and *Rattus tanezumi* were recorded in Peninsular Malaysia. Among these species, *R. tiomanicus* dominated the plantation followed by *R. argentiventer* and *R. rattus diardii*.

Typically, the key rat species present in Peninsular Malaysia's oil palm plantations include *R. tiomanicus, R. argentiventer,* and *R. rattus diardii* (Wood and Chung, 2003; Puan et al. 2011; Bessou et al. 2017). However, species change, or replacement may occur due to several factors. As an example, Effective control of *R. tiomanicus* has paved the way for infestations by *R. rattus diardii* (Wood and Chung, 2003). The formulation and application techniques of the bait have been primarily tailored for *R. tiomanicus*, resulting in the development of resistance in *R. rattus diardii* due to inadequate (sub-lethal dose) consumption of the bait. (Lam et al. 1982; Andru et al. 2013).

### 2.4.1 Malayan Wood Rat, *Rattus tiomanicus*

This predominantly tree-dwelling species is in secondary forests and plantations across the Malay Peninsula (Aplin et al., 2003). In certain regions of Malaysia, *R. tiomanicus* is present in villages, but typically only in areas where its close relative, *R. rattus*, is not found (Paramasvaran et al., 2013). Within oil palm plantations, *R. tiomanicus* frequently seeks shelter in stacks of cut fronds or presumably crowns of palms and occasionally in cut stumps or fallen logs (Buckle et al. 1997). This species was very occasionally discovered in ground burrows, although these are likely dug by other species. If left unmonitored, *R. tiomanicus* has the potential to harm maturing and ripe oil palm fruit, leading to losses exceeding 5% in oil production (Wood,1976). Moreover, the *R. tiomanicus* generally have small home ranging from 1696 $m^2$ (male) and 390 $m^2$ (females) consisting of one or a few adjacent palms. However, the small sample sizes resulted in the not significant difference between the data (Buckle et al. 1997). An estimation of population density of *R. tiomanicus* in unbaited oil palm plantations was recorded from 183-539 individuals per ha, with an average of 306 individuals per ha (Wood and Chung, 2003). Previous records on the physical measurements of *R. tiomanicus* were shown based on a few studies as in Table 2.1.

Table 2.1 Physical measurements of *R. tiomanicus* based on references

| **Physical measurements** | | | | | **References** |
|---|---|---|---|---|---|
| **HB (mm)** | **TL (mm)** | **HL (mm)** | **EL (mm)** | **W (g)** | |
| 154 - 176 | 155 - 198 | 27 -35 | 16 - 22 | 57 - 125 | Aplin et al. (2003) |
| 125 - 180 | 125 - 198 | 28 -32 | 16 -22 | 55 - 152 | Paramasvaran et al. (2013) |
| 125 - 155 | 130 - 159 | - | - | 17 -139 | Verwilghen et al. (2014) |
| 157 - 174 | 144 - 171 | 29 -38 | - | 100 - 130 | Zainal Abidin and Noor Hisham, (2015) |

Note: HB = Head to body length, TL = Tail length, HL = Hindfoot length, EL = Ear length, W = Weight

### 2.4.2 Malaysian house rat, *Rattus rattus diardii*

The Malaysian house rat, *R. rattus diardii*, was recognized as a commensal pest in Malaysia, typically observed in areas surrounding human habitations e.g., rice field, coastal, and urban (Paramasvaran et al., 2013) However, from the late 1980s, the population of *R. rattus diardii* has become more common in oil palm plantations (Hafidzi and Saayon, 2001) causing extreme damage in a wide range of crops in Malaysia. The percentage of palms with fresh rat damage on fresh fruit bunches (FFB), ranged from low to moderate of 5% to 15% (Balasubramaniam and Chung, 2018). In the oil palm plantation, *R. rattus diardii* is known as a proficient climber, it frequently inhabits nests in trees (Aplin et al. 2003). This species was observed in areas characterized by a combination of open spaces with sparse vegetation, interspersed with partial shading from young palm trees. In FELDA oil palm plantation located at Sabah, Malaysia, Phua et al., (2017) reported that *R. rattus diardii* is a an extremely versatile rat species that prevails in the oil palm plantation with mean ranging and nesting area recorded up to 1142 $m^2$. A study conducted by Balasubramaniam and Chung, (2018) using capture, mark, recapture (CMR) technique found that the population of the *R. rattus diardii* ranged from 185 to 718 rats per hectare with an average of 384 rats. The *R. diardii* were synonymous with *R. tanezumi* presumably arose in discrete geographical areas but both rats have similar genetic material, and they were anticipated to exhibit comparable responses in the same environmental conditions, such as under pesticide pressure (Aplin et al. 2003; Musser and Carleton 2005). Previous records on the physical measurements of *R. rattus diardii* are shown in Table 2.2.

Table 2.2 Physical measurements of *R. rattus diardii* based on references

| **Physical measurements** | | | | | **References** |
|---|---|---|---|---|---|
| **HB (mm)** | **TL (mm)** | **HL (mm)** | **EL (mm)** | **W (g)** | |
| 131 - 270 | 130 - 257 | 30 - 40 | 18 -25 | 100 - 290 | Paramasvaran et al., 2013 |
| 150 - 205 | 175 - 231 | 32 - 39 | 19 -25 | - | Aplin et al. 2003 |
| 125 - 200 | 145 - 171 | 30 - 40 | - | 90 - 250 | Zainal Abidin and Noor Hisham, (2015) |

Note: HB = Head to body length, TL = Tail length, HL = Hindfoot length, EL = Ear length, W = Weight

### 2.4.3 Rice-field rat, *Rattus argentiventer*

The rice-field rat, *Rattus argentiventer* is considered as one of prominent rodent pests in numerous islands and mainland regions of Southeast Asia (Aplin et al. 2003). Its evident inclination towards waterlogged areas with dense grassy cover makes it well-suited to live in rice fields. However, in oil palm plantations, *R. argentiventer* is completely terrestrial and resides in burrows (Aplin et al. 2003; Tristiani, 2003). This species evidently adapts less at climbing and is replaced by the arboreal species (*R. tiomanicus* or *R. rattus diardii*) as palms approach five years old, when the fruit bunches are at about one meter height. Thus, young palms are frequently attacked by this species. A radio tracking by Tristiani, (2003) in a rice field in West Java, Indonesia found that, in the breeding season, males exhibited larger home ranges than females (3.20–3.24 hectares compared to 2.51–2.34 hectares), while no sexual differences were observed in the nonbreeding season. The *R. argentiventer* considered as medium-size rat with physical measurements recorded as in Table 2.3.

Table 2.3 Physical measurements of *R. argentiventer* based on references

| **Physical measurements** | | | | | **References** |
|---|---|---|---|---|---|
| **HB (mm)** | **TL (mm)** | **HL (mm)** | **EL (mm)** | **W (g)** | |
| 160 – 194 | 165 - 210 | 34 - 41 | 20 - 24 | - | Aplin et al. 2003 |
| 189 - 202 | 190 -212 | 30 -38 | - | 200 - 270 | Zainal Abidin and Noor Hisham, (2015) |
| 176 - 462 | - | - | - | 21 - 332 | Nasir et al. (2022) |

Note: HB = Head to body length, TL = Tail length, HL = Hindfoot length, EL = Ear length, W = Weight

## 2.5 Quantitative assessment of rat population abundance and damage losses on oil palm fresh fruit bunches

In agricultural sectors, the correlation between pest abundance and crop damage can be intricate (Verbeck, 2011). The studies involved in the correlation between rat population abundance and oil palm fresh fruit bunches (FFB) damage in Malaysian oil palm plantation were varied in different locality. As an example, in a study by Wood and Liau, (1984) in oil palm plantation at Johore, it is approximated that a population of 300 rats in a one-hectare oil palm plantation would consume around 5% of oil palm fruit bunches, resulting in a loss of approximately 240 kg of oil. The amount of damage to palms relates to the population size estimated from amount eaten in captivity. In another study by Puan et al., (2011) in an oil palm plantation at

Labu, Negeri Sembilan found that the levels of damage to oil palm FFB shared a significant positive correlation with the rat relative abundance.

Examining the numerical and functional responses of pests to alterations in food resources will establish a solid foundation for predicting the rates of increase in pest populations (Puan et al. 2012). A study on rats' abundance with rainfall in an oil palm plantation by Nasir et al. (2022) found that the annual precipitation exhibited a negative correlation (-0.258, $p < 0.05$) with species abundance. This indicates that rats were more prevalent during the dry season. The relationship between rat population and intensity of the attack studied by Ikhsan et al. (2020) located in West and Central Sulawesi, Indonesia oil palm plantation found that the addition of one individual rat contributes to a 0.091% increase in the intensity of damage. From the linear regression analysis between population density and rat damage intensity, the P-value $<0.05$ suggests that the intensity of damage to oil palms due to rats is strongly influenced by the abundance of rats (Ikhsan et al., 2020; Nasir et al., 2022).

The management of pests in agricultural systems relies on key concepts such as Economic Injury Level (EIL), Economic Threshold Level (ETL), and Integrated Pest Management (IPM). The EIL, introduced by Stern et al. (1959), defines the lowest pest population density causing economic damage, influenced by factors like crop value, control costs, pest impact, and market conditions (Higley and Pedigo, 1993). ETL, or known as Action Threshold, represents the pest density at which control measures should begin to prevent reaching the EIL, facilitating preventive actions and sustainable practices (Stern et al., 1959; Pedigo et al., 1986). IPM integrates biological, cultural, physical, and chemical methods, emphasizing ecologically based strategies for long-term sustainability and reduced pesticide use (Keasar et al., 2023). A study by Pimentel, (1996) provides examples where IPM has successfully lowered production costs and enhanced biodiversity. For instance, in certain cropping systems, the introduction of biological control agents led to a significant reduction in pesticide applications and an increase in the diversity of beneficial insects. Collectively, EIL, ETL, and IPM offer a comprehensive framework for economically viable and environmentally sustainable pest management.

Controlling pests by mitigating damage to crops effectively, it is essential to forecast population growth rates to ascertain the suitable level, timing, and frequency of control. Implementing control measures after the onset of pest outbreaks is likely to be ineffective, as pest populations are often so elevated at that point that control efforts cannot sufficiently diminish or eliminate the resulting damage. (Wood and Chung, 2003).

### 2.5.1 Potential biological control

During spotlight surveys conducted in the oil palm habitat located in Riau and Bangka provinces, Indonesia, four distinct species of wild carnivores were identified: the leopard cat (*Prionailurus bengalensis*), the Malay civet (*Viverra tangalunga*), the common palm civet (*Paradoxurus hermaphroditus*), and the small-toothed palm civet (*Arctogalidia trivirgata*) (Verwilghen, 2015). Among these, the leopard cat and the common palm civet were the most frequently observed species (Verwilghen, 2015; Hood et al., 2019; Silmi et al., 2021). Rodents constitute approximately 93% of the leopard cat's diet and make it an important part of their diet (Rajaratnam et al. 2007; Silmi et al. 2021Grassman et al. (2005) documented that in a forest in Thailand, the leopard cat demonstrates a mean annual home-range size (utilizing the minimum convex polygon method) of 12.4 km² for males and 14 km² for females.

Within an oil palm-dominated landscape, prey is more plentiful, and the home range size is expected to be smaller. Rajaratnam et al. (2007) substantiated this, reporting annual home-range sizes ranging from 1.9 to 4 $km^2$ in a mixed oil palm and forest landscape in Sabah. Moreover, pig-tailed macaques also have the potential to act as biological pest control by feeding on the rats in oil palm plantation, with each macaque group estimated to reduce rat populations by about 3,000 individuals per year (Holzner et al. 2019).

Birds exemplify ecosystem services that can be harnessed for rodent control. Within the oil palm plantation, numerous endemic nocturnal and diurnal bird species have the capacity to regulate pests, particularly rats (Kamarudin et al. 2019). The most utilized nocturnal birds used in oil palms are the barn owls, *Tyto javanica javanica*. The population of barn owls in Malaysia has experienced a significant increase, correlating with the expansion of the oil palm industry. In 1951, Glenister (1951) categorized the barn owl as 'very rare in Malaya,' with only three or four recorded sightings. However, by the 1980s, Lenton (1980) demonstrated that their numbers were restricted due to a scarcity of nest sites. To address this, he designed nest boxes, leading to successful breeding within plantations.

Later, Lenton (1984) described it as common, and a similar change has occurred in Sumatra (Duckett, 2008). Duckett (1982) consolidated Lenton's research, revealing that barn owls were significant consumers of rats, constituting as much as 98% of their diet. It was estimated that a breeding pair of owls, along with their offspring, could consume between 1200 and 1500 rats annually. In Malaysian oil palm plantation, nest box density ranges from 10 to 30 ha for one box (Noor Hisham and Zainal Abidin, 2013) with a substantial number of nest boxes is typically installed, but this density is gradually reduced as the visible success of rat control is achieved. However, it's important to note that barn owls alone cannot completely regulate the rodent population and the critical damage level on the oil palm fruit bunches need to be breached below the economic threshold level (ETL) of less than 5% by applying chemical rodenticide (Noor Hisham and Zainal Abidin, 2013; Verwilghen, 2015; Zainal Abidin et al. 2021).

### 2.5.2 Anticoagulant rodenticide application in oil palm plantation

Poison baiting using anticoagulants has been the main method of rat control in oil palm plantations (Bessou et al. 2017; Noh et al. 2022; Ravindran, et al. 2022). As the Vitamin-K antagonists, anticoagulant rodenticides disrupt regular blood clotting and cause capillary damage (Watt et al. 2005). When the carcass of an anticoagulated rodent is analyzed, the largest residue of anticoagulant is found in the liver, the site of action (Rached et al. 2020). Anticoagulants are commonly categorized into two groups. The first-generation anticoagulant rodenticide (FGAR) or known as multiple-dose anticoagulants such as warfarin, chlorophacinone, and diphacinone typically necessitate an animal to consume multiple doses of the bait over several days. Second-generation anticoagulant rodenticides (SGAR), also known as single-dose anticoagulants, including brodifacoum, bromadiolone, and difethialone, are more potent. Ingesting the bait for just one day can lead to a toxic dose (Rached et al. 2020).

Following the warfarin resistance in oil palm rats in Malaysian oil palm plantation (Wood and Chung, 2003; Andru et al. 2013; Buckle and Smith, 2015), newer anticoagulants such as brodifacoum and bromadiolone have proved effective to overcome the warfarin-resistance-rats (Noh et al., 2022). A review on development of rodenticide control methods in to control rats in oil palm plantation by Wood and Chung, (2003) stated that the optimum control on rat population could be achieved by application of anticoagulant rodenticide of one bait per palm with replacement rounds of baiting of four days intervals until the bait acceptance decline below 20%. Moreover, the economic threshold level below 5% (ETL) indicated a successful control on rats in the oil palm plantation (Noh et al. 2022). After rodenticide application, the fresh rat damage should be brought down to zero and maintained at that level for several months. According to Wood and Chung, (2003), rat baiting need to be done at six months intervals to ensure an effective in maintaining control of the rat population without allowing the population to recover and cause substantial damage. This systematic approach ensures continuous pressure on the rat population, thereby contributing to long-term pest management success in the oil palm plantations.

Nevertheless, anticoagulant rodenticides (ARs) may pose a secondary exposure hazard to mammalian carnivores that consume rodents, such as leopard cats and civets, as well as raptors that feed on rodents, like barn owls (Ravindran et al., 2022). Domestic livestock and granivorous birds face a high risk of AR exposure through primary exposure to toxic bait, whereas omnivores such as macaques and wild pigs are at a moderate risk for both primary and secondary exposure to ARs (Berny et al, 2018). Moreover, a study by Kotthoff et al. (2018) on ARs residue in fish and suspended particulate matter found that brodifacoum was detected in 88% of the samples with a maximum concentration of 12.5 μg/kg. In contrast, no FGARs were detected in the samples. In certain estates, control is exclusively accomplished through the use of barn owls without resorting to baiting. Most estates in Malaysia carry out baiting in conjunction with barn owl utilization, thereby reducing the overall cost of baiting from RM2.64 to RM30/ha/year (Hafidzi and Saayon, 2001).

The extreme intelligence of rats and due to certain physiological constraints, rats consistently exhibit suspicion. Traits such as neophobia and bait shyness impose limitations on the successful utilization of rodenticides (Chellappan, 2021). According to Chung, (2019), the bait-shy-rats can be overcome by resorting biological control and more recently by shooting, hunting, and trapping. However, the mechanical methods of shooting, hunting, and trapping were labour intensive and have not been evaluated in any reduction in rat population in the field or any significant reduction in crop damage. Hence, rodenticides need to be highly palatable and accepted by rats to control the rat population in oil palm plantation (Clapperton, 2006) and among all of the rodenticides, brodifacoum and chlorophacinone were commonly used in Malaysian oil palm plantations (Zainal Abidin et al. 2021; Noh et al. 2022).

## 2.6 The rodenticides selected for the study

### 2.6.1 Chlorophacinone

Chlorophacinone is one of the FGARs that was first introduced in 1961 and is now widely used to control rat population in urban and agriculture (Pitt et al. 2010; Zainal Abidin et al. 2021). Chlorophacinone has the empirical formula $C_{23}H_{15}ClO_3$ and the chemical structure is as shown in (Figure 2.1). a molecular weight of 364.8, it constitutes a yellow crystalline solid, having a melting point of 140°C. Its solubility characteristics include being slightly soluble in water (100 mg/l at 20°C) and soluble in acetone, ethanol, and methanol. This substance remains stable under typical storage conditions and the plasma half-life was short at 6 to 22 days after ingestion (Watt et al. 2005; Krieger, 2011).

The acute oral LD50 of chlorophacinone against *R. norvegicus* is 20.5 mg/kg (Prescott and Buckle, 2000), and the compound is applied in baits at a concentration of 0.0 05–0.01% against these animals. In a test by Kowalski et al. (2006) demonstrated the high efficacy of chlorophacinone against the California ground squirrel, *Spermophilus beecheyi*, reaching up to 94.2%. Similarly, Salmon et al. (2007) indicated that chlorophacinone effectively managed the California ground squirrel, *S. beecheyi,* with a control rate exceeding 80.0% in cattle-grazed rangeland areas in the

Sierra Nevada foothills and Monterey County, California. In a laboratory study, Marsh et al. (1977) reported that a concentration of 0.005% chlorophacinone achieved complete control against deer mice, *Peromyscus maniculatus*, within four days of a free choice feeding test.

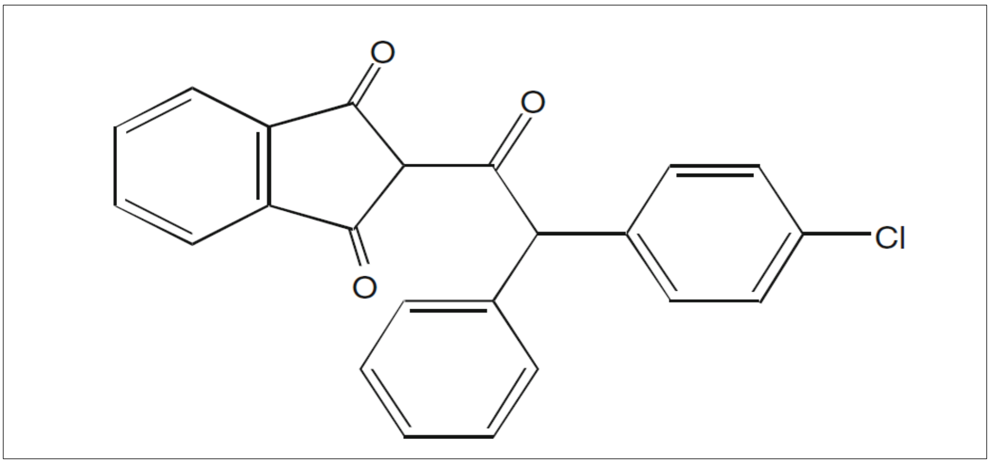


Figure 2.1 Chemical structure of chlorophacinone (Watt et al., 2005)

### 2.6.2 Brodifacoum

Brodifacoum belongs to a SGARs and originally developed in the 1970s to overcome warfarin resistance in rodent populations (Pitt et al., 2010; Noh et al. 2022). In 2018, a multistate outbreak of brodifacoum-tainted synthetic cannabinoids was reported in approximately 300 patients (Krieger, 2011). Generally, the infected individuals exhibit a bleeding diathesis, most frequently characterized by extensive hematuria, oral mucosal bleeding, epistaxis, and gastrointestinal bleeding, however fatalities have also been seen (Chong and Mak, 2019). Brodifacoum has the empirical formula of $C_{31}H_{23}BrO_3$ and the chemical structure is as shown in (Figure 2.2). It has the molecular weight of 523.4 and is insoluble in water. It also has a boiling point of 679°C and melting point of 228 to 230°C.

The biological half-life of brodifacoum is very slow at 20 to 130 days (Watt et al. 2005; Krieger, 2011). A rodenticide field trial in an oil palm plantation located in Sungkai, Perak demonstrated the effectiveness of this compound for the control of warfarin resistant rats (Noh et al., 2022). However, there is currently no recent published report on the effectiveness of brodifacoum baits against specific rat species in oil palm plantations. Utilized in baits at a concentration of 0.005%, brodifacoum has undergone evaluation worldwide, both in laboratory and field settings, and has proven to be effective against all common commensal and agricultural rodent pests it was tested against (Watt et al., 2005). Research indicates that the compound's activity is such that rodents typically succumb to the bait after consuming it as part of their food intake within just one day. Complete eradication of warfarin-susceptible and resistant strains of all three commensal pest species is achieved after 24 hours of exposure to brodifacoum baits. In a field study by Frankova et al. (2019), the highly palatable bait with a low dose of brodifacoum (0.0025%) demonstrated 95.7% and 99.8% efficacy against house mice (*Mus musculus*) in an agricultural building in Prague, Czech Republic. According to Brown and Singleton (1998), brodifacoum proved effective in controlling the population of *Mus musculus domesticus* in Southern Australia. The utilization of highly enticing brodifacoum bait at rates of 1 kg per hectare and 2 kg per hectare via aerial application resulted in a decrease in the mouse population of nearly 99% within seven days of treatment.

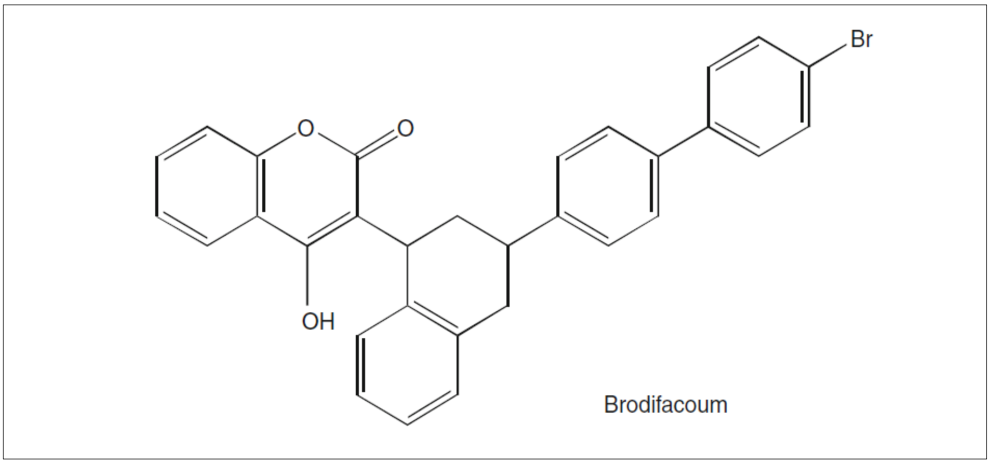


Figure 2.2 Chemical structure of brodifacoum (Watt et al., 2005)

# CHAPTER 3

# SPECIES RICHNESS, ABUNDANCE, AND MORPHOLOGICAL VARIATION

## 3.1 Introduction

Investigating the abundance of local rodent pests, known for causing substantial agricultural losses, is a critical aspect of effective monitoring and control strategies (Verbeck, 2011). Among these pests, the Malayan wood rat (*Rattus tiomanicus*), Malaysian house rat (*Rattus rattus diardii*), and rice-field rat (*Rattus argentiventer*) are commonly found in Malaysian oil palm plantations, as indicated in previous studies (Hafidzi and Saayon, 2001; Aplin et al., 2003; Wood and Chung 2003). The prevalence of these species varies with location, with several studies identifying *R. rattus diardii* as the dominant rat pest in Malaysian oil palm plantations (Puan et al, 2011; Zainal Abidin, and Noor Hisham, 2015; Phua et al. 2017) while others reported the dominant species to be *R. tiomanicus* (Hafidzi and Saayon 2001; Appanan et al. 2021; and Nasir et al. 2022). A potential cause for this is the control of *R. tiomanicus*, which inadvertently boosted *R. rattus diardii* infestations, as bait designed for the former caused resistance in the latter (Lam et al., 1982; Andru et al., 2013). However, the dominant rodent species does not affect the fact that they all cause significant damage to oil palm bunches (Shukor et al., 2018).

Currently, the literature on rodent pest species distributions is lacking, especially in context of the oil palm plantations of southern Perak. This study aims to address these gaps by examining the abundance of non-volant rodent pests using live-trapping methods and assessing physical characteristics of the dominant rodent species. Moreover, the evaluation of physical attributes aids in estimating potential crop damage, ultimately contributing to sustainable and economically viable practices.

## 3.2 Methodology

### 3.2.1 General workflow

In this study, rat specimens were collected utilizing baited traps as the sampling method. The abundance of rodent species was then observed. Following this, the abundance of the most prevalent rodent species was quantified. Additionally, a comparative analysis of body morphology was conducted, considering both geographical sampling locations and sex of the rodents. The schematic representation of the overall workflow is visually depicted in Figure 3.1.

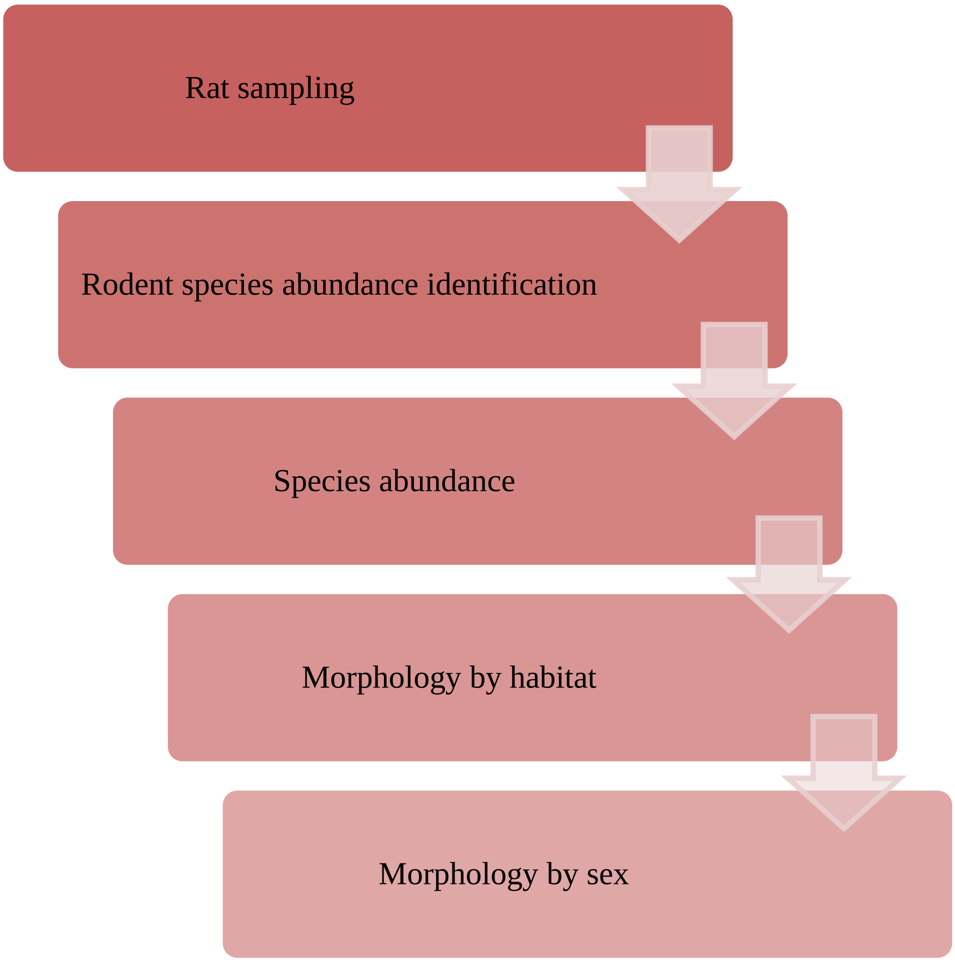


Figure 3.1 General workflow of this study

### 3.2.2 Study area and experimental design

This study was carried out in an oil palm plantation in Sungkai, Southern part of Perak coordinate of 3.726071 N, 101.28444 E (Figure 3.2). The plantation covers 1688 ha of productive 9-year-old oil palms. A total of 30 trapping sites each of three ha were selected randomly with the condition that they were accessible and relatively flat to facilitate traps placement The distance between each plot was 500 metres away to prevent rats from migrating between the plots. From the 30 trapping sites; 15 were located within one kilometre from residential area (Area A) and the other 15 were located more than one kilometre from residential area (Area B). The distance between trapping plot were determined and marked using Map Marker Application as in Figure 3.3.

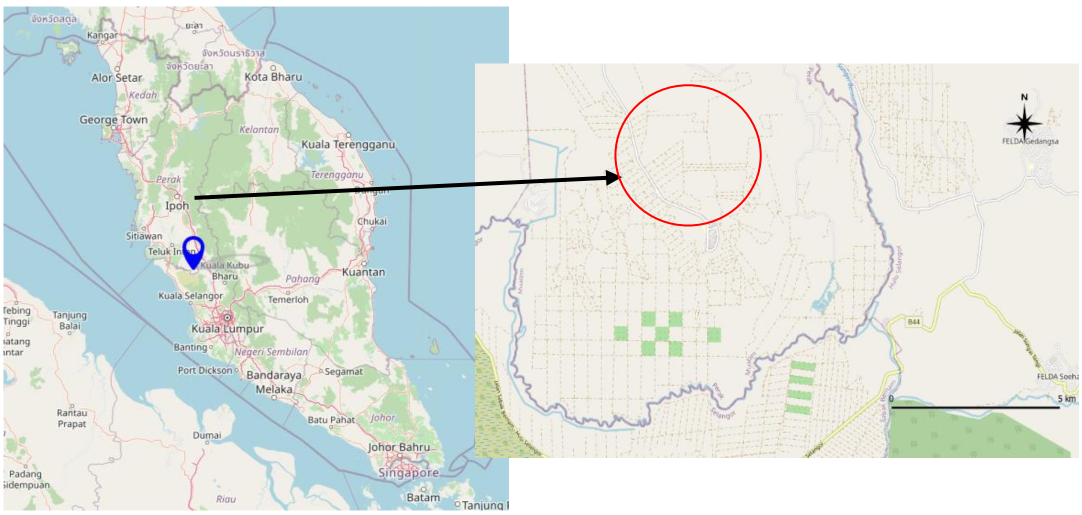


Figure 3.2 The location of study area (red circle) in Sungkai, Perak


Figure 3.3 Determining the trapping plots using Map Marker Apps. The green plot is the Area A and red plot were Area B

### 3.2.3 Rodent sampling

Standard commercial live traps, lured with loose oil palm fruit, were employed to capture rodents (Figure 3.4). A total of 100 traps (28 cm x 15 cm x 12 cm) were set randomly within each study plot for three consecutive nights. If a rat was trapped on the first day, the trap was exchanged with a new one, and the used trap was cleansed with detergent to prevent trap shyness (Ikhsan et al, 2020). The trapped rodents were identified, recorded, marked, and subsequently released. Figure 3.4 Procedure of rodent trapping. (**A & B**) Live traps baited with oil palm loose fruit; (**C**) A trap was placed near the frond piles.